INFLUENCE OF PINE AND BIRCH FORESTS ON THE SOILS OF THE SOUTHERN URALS

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The problem of the interrelationship between woody vegetation and soils has long attracted the attention of investigators since it is of great practical and theoretical importance. It permits the proper conduct of one or the other measures in forestry and promotes the further development of silviculture. These interrelationships are complicated and many-sided and manifest themselves differently under various geographical and ecological conditions (2, 4). They are best known under the level areas of the European USSR. They have been studied little in the Urals and in Siberia, where climatic and soil conditions have specific characteristics.

The present article is devoted to the study of one of the aspects of the foregoing relationship, namely the influence of woody vegetation on soils. We examined certain characteristics of the effect of pine and birch forests on soils. The investigations were conducted in 1957 and 1958 at the V. I. Lenin Il'men' State Reservation.[1]

The Reservation is located in the northern part of the eastern foothills of the Southern Urals. The climate of the Reservation is moderately continental. According to the data of the "Miassovo" meteorological station, the mean annual temperature is 1.8°C, the mean annual precipitation is 454 mm; and the frost-free period lasts 119 days (1). The work was conducted in two permanent and six temporary experimental areas.

The permanent experimental areas (No. 24, a mixed-herbage fern pine stand, and No. 25, a mixed-herbage fern birch stand) are located in the lower part of an eastern slope. The slope does not exceed 5°. Both areas immediately adjoin each other. A clearing the size of a compartment serves as boundary between them. The temporary experimental areas were selected in pairs (pine stand and birch stand) in the same forest vegetation conditions, close to each other, whenever possible (Table 1).

All of the birch stands are naturally produced. We can state more or less definitely that the replacement of pine by birch occurred in the first generation: in almost all experimental areas we found the overgrown remains of semi-decomposed charred pine stumps in the birch stands.

In all cases the soils are sod-podzolic with differing degrees of podzolization. To compare the morphological structure of the soils we give the description of soils in experimental areas No. 24 and No. 25.

Experimental area 24. Mixed-herbage fern stand with a thin undergrowth of broom, mountain ash, and dog rose. The grass cover consists of mixed grasses, herbage, and ferns of an uneven composition and density. There is little sod. Green mosses, predominantly *Pleurozium shreberi*, are found in small patches.

A_0 0-4 cm. Non-decomposed pine litter at the surface. Below — compact, slightly decomposed litter. Contains a lot of fungus mycelium in places. Charcoal is found. The litter is somewhat loosened by grass.

A_1 4-12 cm. Dark-gray. Fine-grained structure, rather stable. Friable. Medium clay loam. Contains many roots, predominantly from grasses. The transition to the underlying horizon is clear in color, density, and structure.

A_2 12-35 cm. Whitish-light-gray. Leafy-porous structure, weak. Medium clay loam with little gravel. The transition is clear in color, density, and structure.

B 35-50 cm. Reddish-cinnamon-brown, nutty-lumpy, compact, fine clay loam, containing somewhat more gravel than the preceeding horizon. Occasionally contains small (5-10 cm in diameter), rolled back fragments.

BC 50-81 cm. Products of rock weathering. Cinnamon-brownish clayey coatings are found on the faces of particles. Strongly skeletal. Poorly-defined structure.

CD 81-110 cm. Weathered rock (gneiss-granite).

Experimental area 25. Mixed-herb fern

[1] The work was conducted under the supervision of Professor S. V. Zonn.

Table 1

Brief evaluation of the tree stands

Experimental area No.	Forest type	Average			Density	Site quality	Composition
		Age	Diameter	Height			
25	Mixed-herb fern birch stand	50	20	24	0,8	II	10 B + P
3	"	45	18	20	1,0	III	10 B
4	"	40	18	21	0,7	III	10 B
5	"	50	20	21	0,9	III	10 B
24	Mixed-herb fern pine stand	120	38	30	0,9	I	10 P
1	Mixed-herb grass pine stand	120	32	26	0,9	II	10 P
2	Grass mixed-herb pine stand	120	28	23	0,8	II	10 P
6	Mixed-herb fern pine stand	43	20	19	0,8	II	7 P3B

Note: Comma represents decimal point.

birch stand with a thin undergrowth of willow and mountain ash. The grass cover consists of mixed herbage and ferns, including legumes and broadleaf grasses; there is little sod. Mosses are rare (Mnyum, etc.).

A_0 0-2 cm. Loose birch litter and grass remains, absent in places. A large amount of caprolite at the boundary between the litter and the mineral horizons of the soil.

A_1 2-14 cm. Dark-gray, becoming lighter with depth; containing darker tongues extending to a depth of 20 cm. Stable, lumpy-granular structure. Friable. Medium clay loam. There is a lot of caprolite in the upper part of this horizon. The transition to the A_2 horizon is clear.

A_2 14-28 cm. Whitish-gray, Weak leafy-porous structure, slightly compacted. Medium clay loam. The transition to the B horizon is clear.

B 28-45 cm. Reddish-cinnamon-brown, nutty-lumpy, compact, fine clay loam, gravelly. The transition to the BC horizon is gradual.

BC 45-75 cm. Products of gneiss-granite weathering. Cinnamon-brown clayey coatings along the faces of structural units.

CD 75-100 cm. Products of gneiss granite weathering.

As we can see from the foregoing descriptions there are noticeable differences in the morphological structure of the soils. They manifest themselves in the thickness, color, structure, and compactness of the A_1 and A_2 horizons. These differences are characteristic of all the soils studied. The thickness of the A_1 horizon in the pine stands varies from 8-11 cm and in the birch stands, from 10-15 cm. The A_2 horizon is thicker in the pine stands than in the birch stands. Its thickness under the pines varies from 16-23 cm, and under the birches, from 13-18 cm. Statistical analysis showed that the difference in the thickness of the A_1 and A_2 horizons of the soils in the pine and birch stands is quite reliable.

The A_1 and A_2 horizons in the pine stand are somewhat lighter in color, have a less stable structure, and, judging by the bulk density (Table 2) are more compact than the same horizons in the birch stand.

The difference in the degree of podzolization is also confirmed by the results of the total

Table 2

Bulk density of the soil, g/cm³

Pine stand, experimental area 24		Birch stand, experimental area 25	
Horizon and depth, cm	Bulk density	Horizon and depth, cm	Bulk density
A_1 4—12	0,95±0,05	A_1 2—14	0,91±0,03
A_2 12—35	1,42±0,03	A_2 14—28	1,31±0,02
B 35—50	1,53±0,03	B 28—45	1,49±0,04
BC 50—81	1,51±0,01	BC 45—75	1,50±0,01

Note: Comma represents decimal point.

chemical analysis of the soils (Table 3). The A_2 horizon of the soil under the pine stand stands out in the distribution of oxides. It is characterized by a high SiO_2 content and a low content of R_2O_3 (especially Fe_2O_3) and of calcium and magnesium oxides. The A_2 horizon of the soil under the birch stand is also pronounced, but less sharply. This indicates that eluviation proceeds more actively under the pine stand than under the birch stand. In the latter, biological accumulation predominates over leaching, judging by the distribution of iron, calcium, and magnesium oxides.

Differences between the soils under the pines and birches also manifest themselves in the amount of humus, exchangeable bases, and soil acidity (Table 4). The upper soil horizons and, especially, the litter are less acid in the birch stand than in the pine stand. The difference in acidity levels off with depth and the acidity of the BC and CD horizons is the same. This is attributable to differences in the acidity of the litter and its distribution.

The upper soil horizons in the birch stands have a higher humus and exchangeable base content. There is also a higher amount of mobile iron compounds in the upper soil horizons under the birch stands.

All this indicates that present soil formation proceeds differently in soils under pine and birch stands.

What are the reasons for these differences? As we have already noted, all experimental areas are located in similar forest vegetation conditions and on the same soil-forming parent material. The only difference between the experimental areas consists in the composition of vegetation. Consequently, the difference in the nature of soil formation must be attributed to the difference in the effect of woody as well as of the grassy vegetation accompanying it.

The influence of woody vegetation on soils is determined first of all by the intensity and nature of the biological cycle (2, 4, 5).

We can see that the main members of the biological cycle are: 1) the requirement of nitrogen and ash elements from the soil by plants, 2) their return to the soil, and 3) the rate and nature of the decomposition of plant residues.

We determined the amounts of substances utilized and returned by the plant tops. This has allowed us to judge of the comparative intensity of the biological cycle in various types of forests.

The requirement of nitrogen and ash elements by plants from the soil consists of the amount of substances used for the annual growth increment of wood, needles and leaves, shoots, fruits, seeds, and the grass and moss cover.

The amount of vegetative mass forming annually was determined in the following manner. The increment of needles and leaves was conditionally taken as equal to their annual fall. To determine the fall in the permanent experimental areas, five collectors, each 1 m² in area, were set up. The accuracy of this method of determining the amount of needles and leaves shed was 5%-10%. The annual increment in wood and branches was determined from growth tables (5).

The amount of grassy vegetation was determined by cutting it 5 times from 1 m² areas.

The amount of vegetative mass forming annually is shown in Table 5.

More vegetative mass forms in the birch stand than in the pine stand; the difference is especially great in the amount of wood and grass-moss vegetation. There was more of the vegetative mass (fruits, shoots, and bark scale) in the pine stand than in the birch stand.

Differences in the amount and composition of

Table 3

Total chemical analysis of soils, % of ignited sample

Experimtl area No.	Horizon and depth, cm	Ignition losses	SiO_2	R_2O_3	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
24	A_1 4—12	12,78	67,95	21,91	2,38	18,09	1,44	4,10	1,84	6,4	75,8	11,8
	A_2 12—35	5,14	70,12	18,69	2,07	15,97	0,65	3,23	1,25	7,5	90,0	12,0
	B 35—50	6,18	58,71	30,15	3,45	26,00	0,69	4,86	2,16	3,8	43,6	11,8
	BC 50—81	7,96	63,70	23,96	2,58	20,70	0,68	5,05	3,87	5,2	65,5	12,5
	CD 81—110	2,22	63,83	24,41	2,84	20,78	0.50	4,30	0,92	5,2	59,7	11,4
25	A_1 2—14	14,43	67,26	21,46	3,24	17,15	1,07	4,98	3,99	6,5	55,1	8,3
	A_2 14—28	6,82	68,52	19,22	2,84	15,72	0,66	4,19	2,30	7,4	64,2	8,7
	B 28—45	7,84	61,51	28,33	3,75	23,85	0,73	4,99	2,54	4,4	43,6	9,5
	BC 45—75	4,61	61,34	23,66	3,30	20,15	0,21	4,80	2,60	5,2	49,3	9,5
	CD 75—100	4,88	66,68	24,68	2,90	21,51	0,27	4,56	1,64	5,2	61,4	11,7

Note: Comma represents decimal point.

Table 4

Brief physicochemical description of the soils

Pine stand

Experimntl. area No.	Horizon and depth, cm	pH of water suspension	Humus (accord. to Tyurin) %	Exchangeable bases, meq/100 g of soil: Ca^{++}	Mg^{++}	Total	Mobile Fe_2O_3 (accord. to Kirsanov), mg/100 g of soil
24	A_0 0—4	5,1	—	51,0	14,5	65,5	17,5
	A_1 4—12	5,2	2,43	8,8	2,4	11,2	18,0
	A_2 12—35	5,3	0,54	8,0	1,9	9,9	28,0
	B 35—50	5,6	0,47	19,4	16,4	35,8	92,0
	BC 50—81	5,4	0,31	25,9	21,8	47,7	36,0
	C/D 81—100	5,5	0,14	21,4	9,9	31,3	—
1	A_0 0—5	5,0	—	—	—	—	16,0
	A_1 5—14	5,6	3,9	13,8	3,9	17,7	18,0
	A_2 14—27	5,8	0,9	8,5	3,1	11,6	19,0
	B 27—46	5,9	0,4	15,0	6,8	21,8	27,0
	BC 46—64	5,8	0,2	10,1	4,6	14,6	27,0
	CD 64—80	5,6	0,2	6,4	2,6	9,0	21,0
2	A_0 0—3	5,5	—	—	—	—	—
	A_1 3—14	5,4	4,3	15,1	5,2	20,3	—
	A_2 14—30	5,3	1,1	9,0	3,8	12,8	—
	BC 30—63	5,4	0,5	12,7	5,1	17,8	—
	CD 63—102	5,5	0,3	11,4	4,5	15,9	—
6	A_0 0—3	5,6	—	—	—	—	11,0
	A_1 3—11	5,8	2,9	15,7	11,8	27,5	57,0
	A_2 11—34	5,3	0,7	8,3	4,3	12,6	43,0
	BC 34—49	5,6	0,6	2.4	1,1	3,5	41,0
	CD 49—70	5,3	0,9	2,1	0,8	2,9	—

Birch stand

Experimntl. area No.	Horizon and depth, cm	pH of water suspension	Humus (accord. to Tyurin) %	Exchangeable bases, meq/100 g of soil: Ca^{++}	Mg^{++}	Total	Mobile Fe_2O_3 (accord. to Kirsanov), mg/100 g of soil
25	A_0 0—2	6.0	—	55,2	19,5	74,7	87,7
	A_1 2—14	5,8	4,6	17,0	3,4	20,4	42,2
	A_2 14—28	6,0	1,1	9,8	2,6	12,4	16,2
	B 28—45	5,8	0,9	10,3	3.2	13,5	31,1
	BC 45—75	5,6	0,8	23,6	14,8	38,4	14,0
	CD 75—100	5,6	0,4	7,6	4,7	12,3	5,8
3	A_0 0—1	6,1	—	—	—	—	—
	A_1 1—11	5,7	7,5	22,5	7,3	29,8	—
	A_2 11—24	5,4	2,2	14,4	5,2	19,6	—
	B 24—32	5,6	1,8	18,4	6,9	25,2	—
	BC 32—49	5,3	0,6	16,3	6,4	22,7	—
	CD 49—83	5,4	0,2	15,2	6,6	21,8	—
4	A_0 0—1	5,8	—	45,1	18,6	63,7	—
	A_1 1—15	6,0	5,8	23,3	8,5	31,8	—
	A_2 15—30	5,9	0,5	8,1	2,8	10,9	—
	B_1 30—63	5,7	0,2	13,3	5,1	18,4	—
	CD 63—105	5,6	0,2	9,0	2,9	11,9	—
5	A_0 0—2	6,0	—	—	—	—	32,0
	A_1 2—17	6,2	5,3	27,2	12,1	39,3	23,0
	A_2 17—35	5,8	1,4	14,3	7,2	21,5	23,0
	B 35—67	5,6	0,8	7,9	3,6	11,5	55,0
	CD 67—100	5,5	0,3	8,7	2,6	11,3	16,0

Note: Comma represents decimal point.

Table 5

Amount and composition of the annually forming vegetative mass, kg/ha

Experimental area No.	Forest type	Woody vegetation				Grass-moss vegetation	Total
		Wood	Needles-leaves	Other	Total		
24	Mixed-herb fern pine stand	3000	1210	756	4966	1400	6366
25	Mixed-herb fern birch stand	4500	1640	403	6543	2100	8643

the vegetative mass forming annually also determine the difference in the requirement of nitrogen and ash substances from the soil (Table 6). Nitrogen and ash substances are used primarily for the formation of grass vegetation both in the pine and in the birch stand. It uses up almost half of all the substances, which is attributable, first of all, to its high ash content which reaches 10% in grasses.

Needles and leaves occupy the second place in the amount of substances they use, but there are considerable differences between the two. The ash and nitrogen content is more than twice as high in birch leaves than in pine needles.

The amount of nitrogen and ash substances used to produce the current increment of wood is of little importance in the total requirement of the foregoing elements. This is attributable to the low ash content of wood, which does not exceed 1%-2%. The consumption of these elements in the formation of fruits, shoots, and bark scale (other parts), which require little nitrogen and ash substances, is also of little importance in the total amount of substances used.

As far as the requirement of individual elements is concerned, the greatest difference between the pine and birch stands is in the uptake of calcium, magnesium, and iron. The birch stand consumes almost three times more of these substances than the pine stand, and more than twice as much as the other substances, except for SiO_2, which is used almost in the same amounts.

Table 6

Amount of nitrogen and ash substances used, kg/ha

Exper. area No.	Item	N	SiO_2	R_2O_3	Fe_2O_3	P_2O_5	K_2O	CaO	MgO	SO_3
25	Leaves	48,2	7,4	11,7	3,6	5,1	21,2	32,9	12,5	5,7
	Other parts	2,7	0,8	1,1	0,2	0,7	1,7	1,7	0,8	3,1
	Wood	9,1	0,5	7,7	0,5	3,2	5,8	11,0	3,6	8,2
	Grass cover	40,0	53,4	11,3	2,5	13.0	59,5	45,0	18,9	19,8
	Total	100,0	62,1	31,8	6,8	22,0	88,2	90,6	35,8	36,8
24	Needles	18,4	0,8	4,6	0,8	2,7	6,3	9,9	3,4	4,9
	Other parts	3,0	3,8	5,4	0,4	1,1	2,7	2,8	0,9	4,7
	Wood	5,5	0,3	6,7	0,7	1,8	3,4	5,8	1,5	2,0
	Grass cover	21,6	44,0	2,5	0,7	5,7	34,4	18,9	8,4	13,3
	Total	48,5	48,9	19,2	2,6	11,3	46,8	37,4	14,2	24,9

Note: Comma represents decimal point.

There is also a difference in the order of distribution of elements taken up from the soil. The birch stand consumes a maximum amount of nitrogen, calcium, and potassium. Silica is in fourth place. Phosphorus and iron are in last place. The order is different in the pine stand: silica occupies the first place, then nitrogen, potassium, and calcium. The order of distribution of the other elements is the same as in the birch stand.

The basic mass of the substances used is returned to the soil with the litter, and only an insignificant amount is retained in the current wood increment.

Substances which enter the soil with the litter are included in the cycles only as the litter decomposes. Therefore, the rate at which litter decomposes is of great importance in the biological cycle. The rate may be determined by the amount of litter. The amount of litter in the birch stand is 5-6 metric tons/ha of air-dry mass, and in the pine stand it reaches 20-25 metric tons/ha. A comparison between the amount of litter and the amount of annual fall shows that the amount of litter in the pine stand exceeds the amount of fall 6-7 times, while in the birch stand it does not exceed by more than 1.5 times. The litters differ also in their ash composition (Table 7).

The content of iron and potassium in the birch litter is more than two times higher than in the pine litter; and that of total nitrogen is 1.5 times higher. The phosphorous and calcium content is somewhat higher in the birch litter. There is more silica and magnesium in the pine litter.

When comparing the ash content of the vegetation and of the litters we can see clearly that it is higher in the latter, especially in the birch litter. The birch litter accumulates iron while the pine litter accumulates silica. Calcium and magnesium are almost completely leached as both litters decompose.

Judging by the morphological structure of the litters, the process of their decomposition differs in the birch and the pine stands. This is also confirmed by the composition of humic substances, which depends not only on the composition of the plant residues, but also to a great extent on the nature of their decomposition (Table 8). The humic acid content is higher in the birch litter than in the pine litter, a fact which is confirmed by the ratio between the C of humic acids and the C of fulvic acids.

It must be noted that in the birch litter there is somewhat more carbon of humic compounds bound with calcium and magnesium and less carbon of substances extractable with benzene alcohol. Acids forming during the decomposition of the litter are neutralized only by bases contained in the litter itself. But, as already mentioned earlier, the vegetation in the pine stand contains almost 4 times less calcium and magnesium than that in the birch stand. As a result, considerably more acid products of decomposition, unsaturated with bases, form in the main litter. The difference in the acidity of the litters is also enhanced by the fact that the plant residues themselves which

Table 7

Content of nitrogen and ash elements in the litter, % of absolutely dry matter

Experimental area No.	N	SiO_2	R_2O_3	Fe_2O_3	P_2O_5	K_2O	CaO	MgO	SO_3	Total	Admixture
24	0,99	4,10	0,82	0,27	0,31	0,45	0,48	0,27	0,48	7,18	5,53
25	1,54	3,96	1,58	0,76	0,40	1,01	0,53	0,19	0,57	9,00	9,87

Note: Comma represents decimal point.

Table 8

Composition of humic substances in litters, carbon of various fractions in % of total carbon in the soil

Experimentl. area No.	Initial C, % of litter weight	C in the benzene alcohol extract	C of substances extracted with soil decalcification	C of humic acids: Fractions I	C of humic acids: Fractions II	C of humic acids: Total	C of fulvic acids: Fractions I	C of fulvic acids: Fractions II	C of fulvic acids: Total	C of residue	Total	C of humic acids / C of fulvic acids
24	30,42	10,23	1,18	1,05	3,02	4,07	4,18	0,89	5,07	76,00	96,55	0,80
25	23,61	9,50	1,89	1,42	4,75	6,17	4,44	1,05	5,49	72,60	95,66	1,12

Note: Comma represents decimal point.

form the litter vary in acidity: the pH of the water suspension of pine litter is 5.7 and that of the birch litter is 6.9.

The acid products of litter decomposition, which are not saturated with bases, determine the processes of podzolization when they penetrate into the lower-lying mineral soil horizons and interact with them.

Conclusions

1. When pine stands are being replaced by birch stands under conditions of the Il'men Reservation, the process of podzol formation is suppressed.

2. The qualitative composition of litter and the nature and conditions of the decomposition of the forest litter play a decisive part in the effect of various woody plants on soils.

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